The Sewer Research Station in Frejlev

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The Sewer Research Station in Frejlev

Annual Report - 1999

Thorkild Hvitved-Jacobsen and Kjeld Schaarup-Jensen
May 2003

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FRONT-PAGE PHOTO (by Flemming Schlütter, former assist. professor at AAU):

The Frejlev North rain gauge - on top of the monitoring structure.

PREFACE

During late fall 1996 the sewer research and monitoring station in Frejlev was completed, jointly financed by Aalborg Municipality and Aalborg University. The year 1997 was used to get the rather new and complicated apparatus for rainfall, flow and water quality parameters including data transmission to Aalborg University in proper operation. This annual report for the year 1999 activities at the station in Frejlev is the second one issued. It is the objective not just to produce an annual overview for internal reasons but also to inform interested researchers and practitioners outside Aalborg Municipality and Aalborg University on the unique possibilities, which exist.

It is an important feature of the sewer monitoring station that dry as well as wet weather aspects can be dealt with. The ambition for Aalborg Municipality and Aalborg University is that the station will serve the dual purpose of being a site for the research on sewer systems and processes at the Department of Civil Engineering as well as a possibility for the establishment of continuous high quality time series of sewer related parameters, e.g. flow.

Only few - if any - sewer monitoring stations like the one in Frejlev exist. Without no doubt the field data produced - especially the time series - in the course of time will serve as a unique basis for projects dealing with the improvement of sewer design and performance. Several researchers and institutions outside Denmark have already visited the field station and shown their interests in the results obtained. To observe future needs for information on the station, it was therefore decided right from the beginning to produce the annual report in English.

Aalborg, May 2003

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In association with

The City of Aalborg
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1. INTRODUCTION

During autumn 1996 a research and monitoring facility was constructed as a part of the intercepting sewer from Frejlev, a small town located 7 km Southwest of Aalborg, Denmark. The construction of this station was made possible due to an outstanding foresight from the Municipality of Aalborg, Denmark. Besides giving the permission for the installation of the necessary structures in the sewer system, the local authorities financially supported the project in co-operation with Aalborg University, Faculty of Engineering and Science.

Frejlev is a town with about 2000 inhabitants and without significant industries. The total catchment covers an area of 85 ha situated on a hillside which slopes down in a northern direction from an uphill level approximately 55 m above sea level to a downhill level 15 m above sea level. The catchment is mainly provided with combined sewers, figure 1.

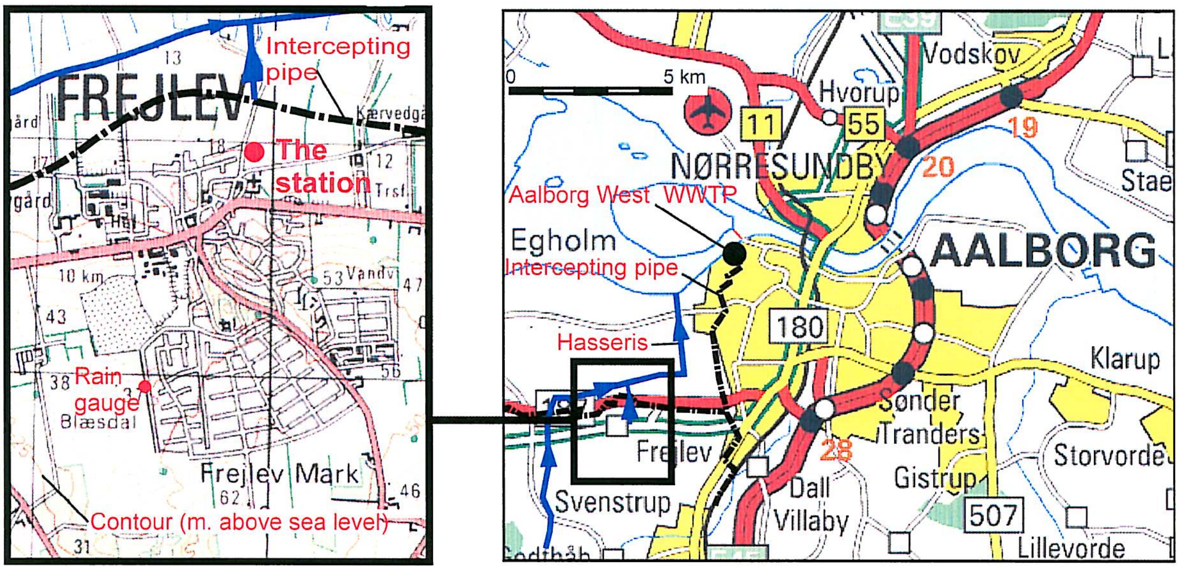

Figure 1 : Aalborg and the experimental site including the town of Frejlev, the Hasseris stream and the Aalborg West WWTP.

During dry weather conditions the wastewater flow is diverted to a wastewater treatment plant Aalborg West in a 300 mm diameter interceptor sewer starting in a combined sewer overflow (CSO) structure located downhill and about 500 m north of Frejlev. This CSO structure diverts the sewage from Frejlev in a 1000 mm diameter combined sewer. During wet weather conditions, CSO's are discharged into Hasseris stream, which flows into the Limfjord about 6 kilometres Northeast of Frejlev.

The long-term measurements in the station will comply with the objectives to create the basis of knowledge on e.g.:

- long term time series containing seasonal as well as diurnal variations in dry weather flow and concentrations of pollutants
- rainfall - runoff relationships,
- the distribution of storm water concentrations of relevant pollutants - including relationships of the level of concentration with rainfall as well as sewer system characteristics.

Furthermore, the measurements can form the basis of a better understanding of transport and transformations of particulate and soluble pollutants in combined sewers including suspended and bed load characteristics and information on processes like sedimentation, resuspension and microbial transformations (Hvitved-Jacobsen et al., 1997; Schlütter and Schaarup-Jensen, 1997; Tanaka and Hvitved-Jacobsen, 1997; Vollertsen and Hvitved-Jacobsen, 1997).

In addition, the variability of urban runoff and wastewater flow parameters as well as quality characteristics is known to be significant and often the standard deviation of a quality parameter is of the same order of magnitude as the corresponding mean value, (Johansen, 1985; Harremoës, 1988; Hvitved-Jacobsen and Yousef, 1991; House et al., 1993). It is evident that design and operation of sewer systems and their interactions with the entire urban wastewater system, i.e. wastewater treatment plants (WWTPs) and local receiving waters, is highly dependant on a detailed knowledge of this variability.

In publications on sewer system measurements, dry weather flow seems to hold a secondary position compared to wet weather flow. In many ways this is surprising because pollutant loads and quality variations during dry weather conditions are important for operation and maintenance of the sewer system itself as well as for the WWTP. Furthermore, only through continuous measurements during dry weather conditions it will be possible to identify if a sewer has a poor or a good natural purification capacity and measurements are necessary to understand why this is (or is not) the case. This knowledge is - due to resuspension of pollutants settled during dry weather conditions - crucial to the determination of pollutant loads which during wet weather are diverted to either WWTPs or discharged into receiving waters via a CSO structure. It is therefore concluded that long term high quality measurements during both dry and wet weather conditions are important to obtain a better understanding of transport and transformation of pollutants in sewer systems.

Concerning the applicability of future water quality and hydraulic time series from Frejlev, it will not be possible to make general conclusions until similar measurements are performed elsewhere. The need of doing so is evident and will become more and more required concurrently with the appearance of more and more complicated numerical computer models capable of simulating flow as well as transport and transformation of pollutants in sewer systems, WWTP and receiving waters. Vital for the reliability of simulations with such models are a number of conditions, e.g. the mathematical model, the (numerical) method of simulation and the degree of knowledge of the system to be simulated. In case of sewer systems this includes knowledge of local time series for a number of model input and/or output parameters in order to perform a model calibration and validation before any further use of the model is possible. Omitting the model calibration and validation process and just finding values of parameters in the scientific literature can typically only provide the user of the model with some general and perhaps misleading simulation results

2. THE STATION

2.1 OVERVIEW OF THE SYSTEM

On average the 2000 inhabitants in Frejlev produce 4-5 l/s of wastewater. Rather sporadic flow measurements in the Frejlev sewer indicate that no infiltration from groundwater aquifers takes place and the dry weather flow is expected to have a diurnal variation between 0 and approximately 10 l/s. During wet weather, a 85 ha catchment with a reduced area of approximately 30 ha and a time of concentration of 20 min will produce a maximum flow of 3800 l/s according to the rational method and a rainfall intensity of 128 l/(ha·s) which in Denmark appears with a return period of 5 year on average. From the very beginning it was an indispensable requirement that dry weather flow as well as wet weather flow at a reasonable limit (return period of 5-10 years) could be recorded by the flow monitoring equipment. This meant that this equipment should have a capacity of performing high quality flow measurements of the interval of 0-3800 l/s

As no commercial available flow meter today has the capacity of producing high quality flow measurements within such an interval, it became clear that the original single pipe stretch of the sewer had to be divided into 2: a 300 mm diameter 'dry weather pipe' and a 1000 mm diameter 'wet weather pipe'. This basic demand determined the design concept, figure 2.

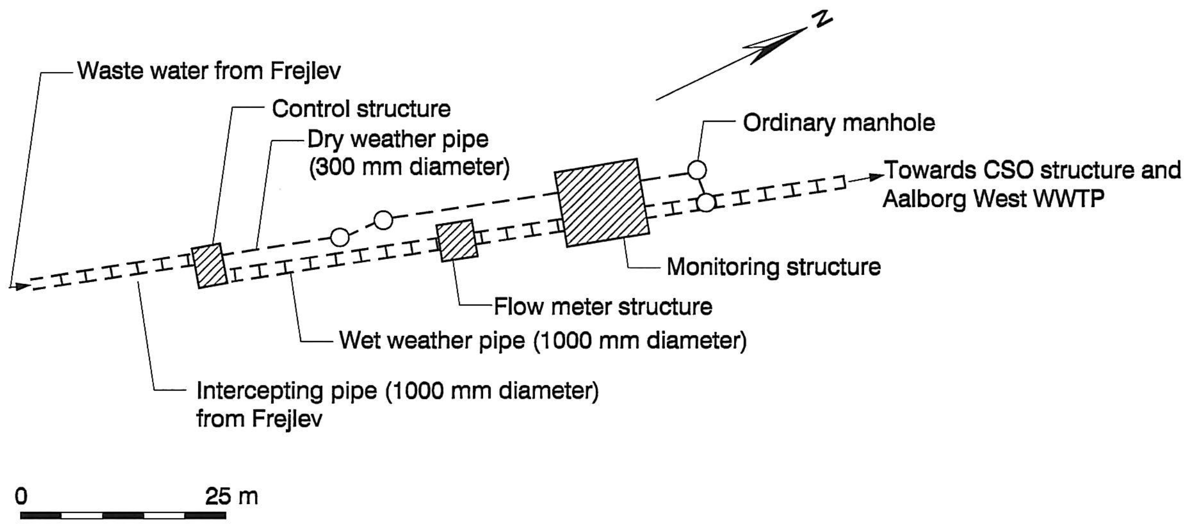

Figure 2: The research and monitoring station upstream the CSO structure of the Frejlev sewer system interceptor.

In order to control in which pipe the flow should take place, the monitoring stretch is equipped with a control structure having a sliding gate which will close the inlet to the small pipe when the flow due to e.g. rainfall runoff is higher than a predetermined value, figure 3. In this way mixed wastewater and runoff water is diverted to the big pipe. When the flow in this pipe is reduced to a certain value, the opposite procedure will take place. This means that future rainfall runoff hydrographs must be formed based on a superposition technique.

2.1 THE FLOW MEASUREMENT SYSTEMS

The dry and the wet weather pipes are equipped with high quality electromagnetic flow meters of the Parti-Mag type manufactured by Bailey-Fischer and Porter. According to technical specifications, these two flow meters are able to produce high quality flow measurements in the intervals 1-700 l/s for the small pipe and 50-7800 l/s for the big pipe with a maximum flow rate error of 1-1.5% of rating. The flow meter supplier has specified a simple set of installation requirements demanding a straight pipe section without any hydraulic disturbances within a distance to a flow meter of 15 times the diameter - distributed with 10 and 5 times the diameter in upstream and downstream directions, respectively. For this reason the wet weather flow meter has been placed in its own structure, figure 2 and figure 4.

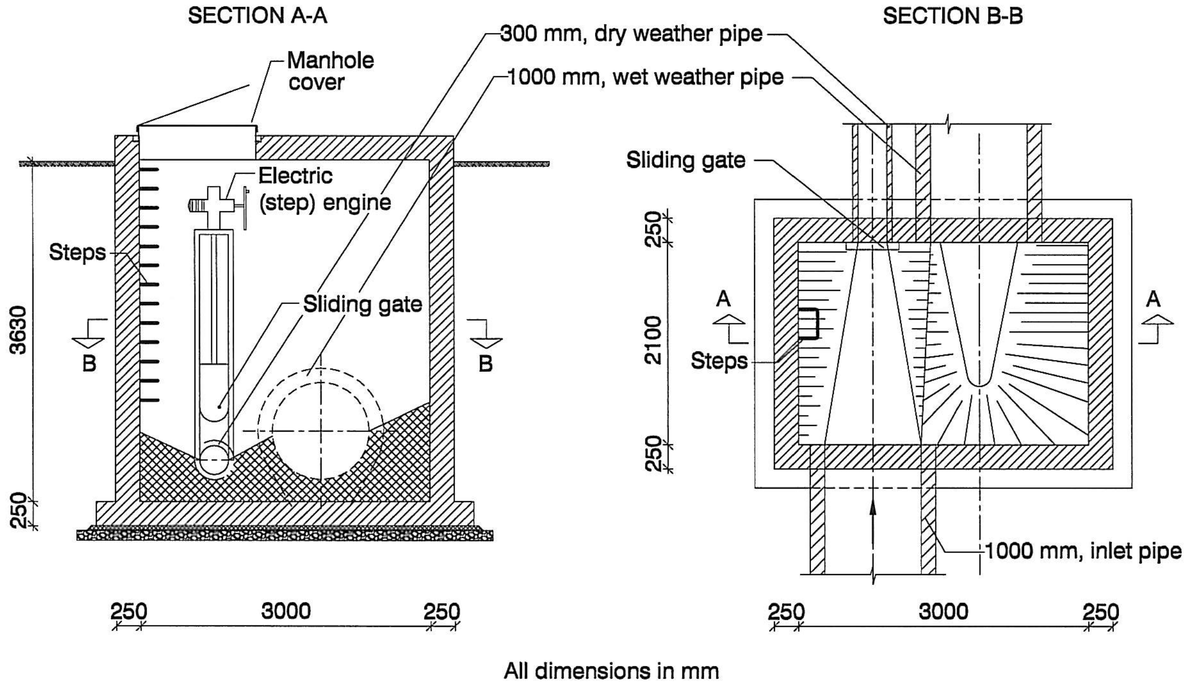

Figure 3: Control structure, upper end of measurement system stretch.

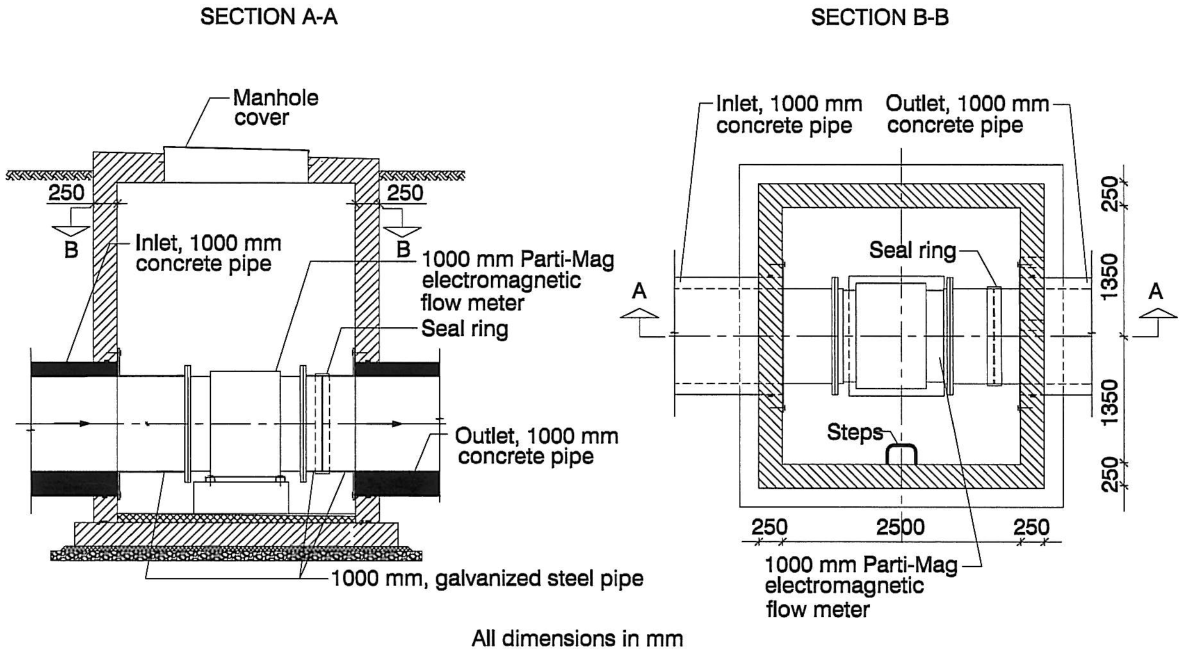

Figure 4: Electromagnetic 1000 mm diameter flow meter placed in a separate structure.

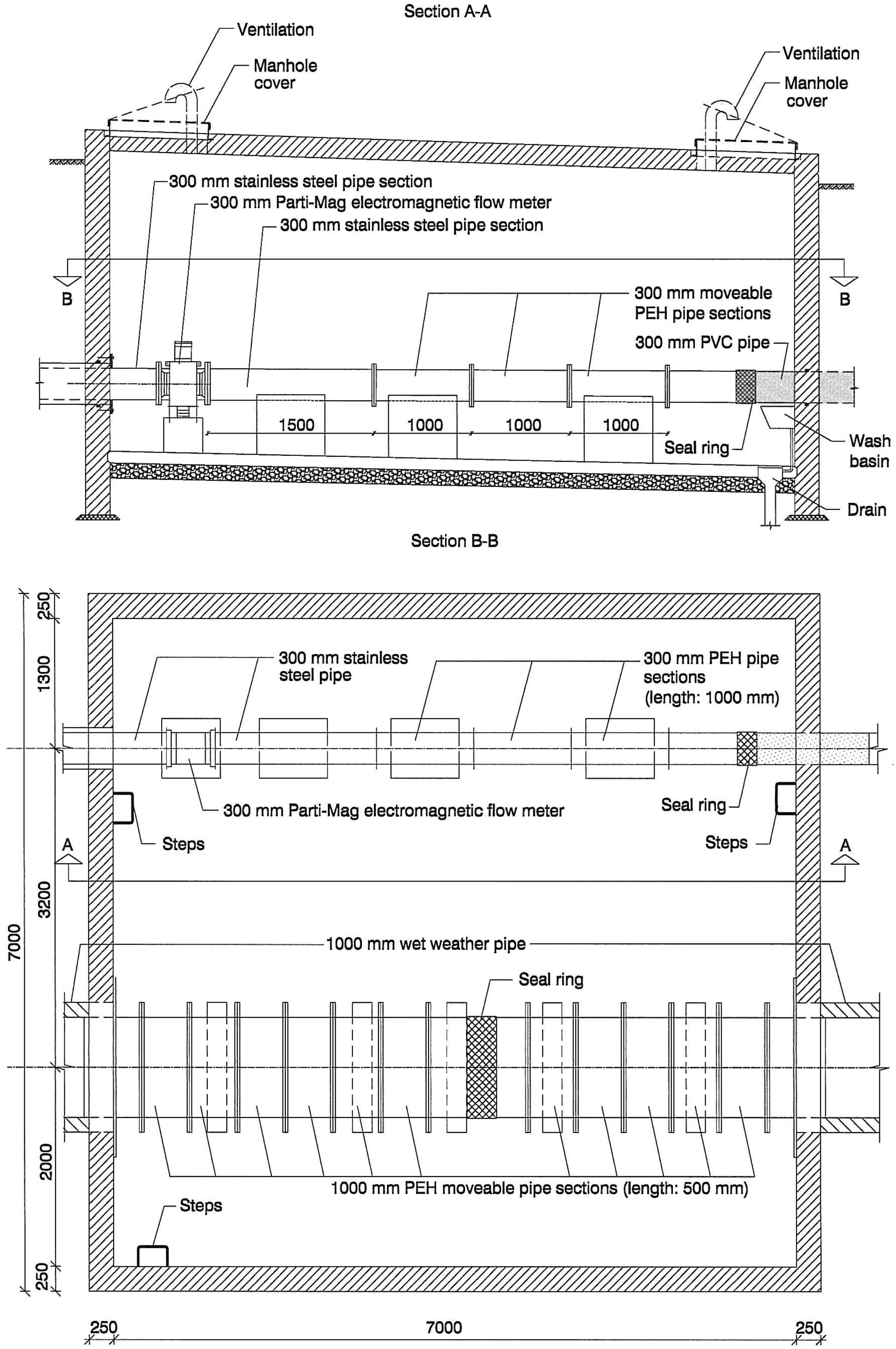

Figure 5: The monitoring structure.

The small pipe flow meter is placed in the monitoring structure itself, figure 5, as a 'hydraulics safety zone' of only 1.5 m was needed in the downstream direction at this flow meter, leaving enough space for other measurement arrangements. From the control structure down to the monitoring structure, all pipes are made of concrete. In order to have manually removable pipe sections within the monitoring structure, polyethylene (PEH) was chosen as pipe material. The length of each section is 1 and 0.5 m for the small and the big pipe, respectively. For the big pipe sections, this results in a weight of approximately 50 kg, which can be relatively easily handled.

2.3 MEASUREMENT SYSTEMS FOR WASTEWATER AND STORMWATER QUALITY

In addition to the flow meters, the monitoring station is equipped with water samplers and sensors for measurements of wastewater quality parameters depending on actual needs. Sampling for analysis of wastewater components and parameters will be carried out depending on specific research project requirements or performed according to specific defined procedures in case of e.g. expected extreme runoff events. Furthermore, growth of biofilms for analysis or laboratory investigations is possible at the surface of the PEH sections of the sewer pipes and experiments on e.g. sediment microbial processes and resuspension of sewer sediments can be carried out using silt traps. The dry weather pipe is equipped with a device that allows to operate separately with a waste water outflow from the pipe of approximately 1 l/s.

2.4. SUPPLEMENTARY EQUIPMENT

On the 'roof' of the measurement structure an automatic rain gauge station (Frejlev North) is placed which in addition to a rain gauge at the uphill part of Frejlev (Frejlev South) have become a part of the national rain gauge system managed by the Danish Waste Water Control Committee and operated by the Danish Meteorological Institute (DMI). Data from the rain gauge at the monitoring station will become a part of the total set of data transmitted to Aalborg University, Department of Civil Engineering, as an almost continuous time series. Data from the second rain gauge will be accessible via DMI.

In order to ensure efficient transmission of data, the monitoring station is equipped with 2 mobile and wireless radio stations each capable of transmitting - as VHF signals - 5 analogous and 8 digital data signals to a receiver station set-up at the university campus. From this main station, the 10 analogous and 16 digital data channels can be monitored continuously. Furthermore, the data transmission system works as a small scale real time processing unit and a digital signal can be transmitted to the monitoring station, e.g. in order to start a pump or a water sampler. All data series are stored on a PC connected to the main station at the university campus. From here data can be stored on a long-term basis on CD-ROM disks.

3. MEASUREMENTS IN 1999

The flow meters were installed in the beginning of 1997. However, initial problems with the 2 meters had to be overcome. These problems resulted in a new-calibration of the two meters in the Bailey, Fischer and Porter factory in Göttingen, Germany, in spring 1998. For this reason the 1997 flow measurements were considered too uncertain for publication and consequently no 1997 annual report has been produced.

After new-calibration of the flow meters they were reinstalled in Frejlev in August 1998 and since early September 1998 the two meters have been working satisfactory according to the specifications.

3.1 RAINFALL MEASUREMENTS

During 1999 the rain gauges in Frejlev, Frejlev North and Frejlev South, have been working extremely well as the outfall periods totally amount to 0.3% of the time (Nielsen, 2000). Monthly precipitation values of 1999 from the two rain gauges are illustrated in figure 6 together with monthly mean values (1961-1990) from the DMI rain gauge station in Tylstrup (Frich et al., 1997), 15 kilometres North of Aalborg. According to Frich et al. the mean annual precipitation in Tylstrup and Frejlev is of the same order of magnitude, 650 mm.

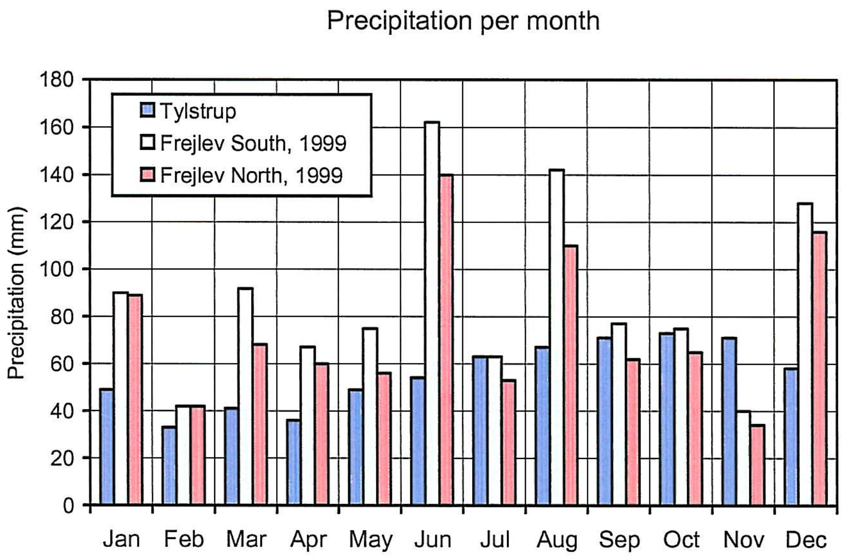

Figure 6: Precipitation per month measured at Tylstrup (mean, 1961-1990), Frejlev North and Frejlev South (1999).

The 1999 annual precipitation at the Frejlev North and South rain gauges were 895 mm and 1057 mm, respectively. Thus the annual precipitation at the southern station exceeds the corresponding northern value with 18% - a remarkable difference as the 2 rain gauges are placed approximately 700 m apart. In 1998 this difference reached 15% - cf. figure 7.

From figures 6 and 7 it is evident that both 1998 and 1999 can be characterized as "wet years".

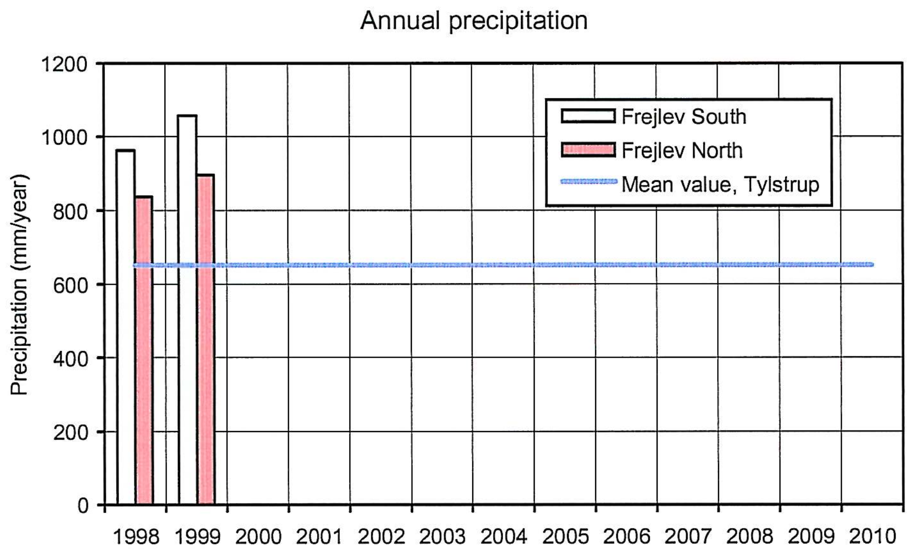

Figure 7: Annual measured precipitation, Frejlev North and South, 1998-1999, compared to Tylstrup mean value, 1961-1990.

In total 303 and 289 rainfall events have been recorded by the 2 rain gauges in Frejlev during 1999. I.e. 5% of these rainfall events have only occurred in the southern catchment of the city.

The 303 rainfall events recorded at the Frejlev South rain gauge station have been analyzed in order to describe the rain depth distribution – cf. figure 8:

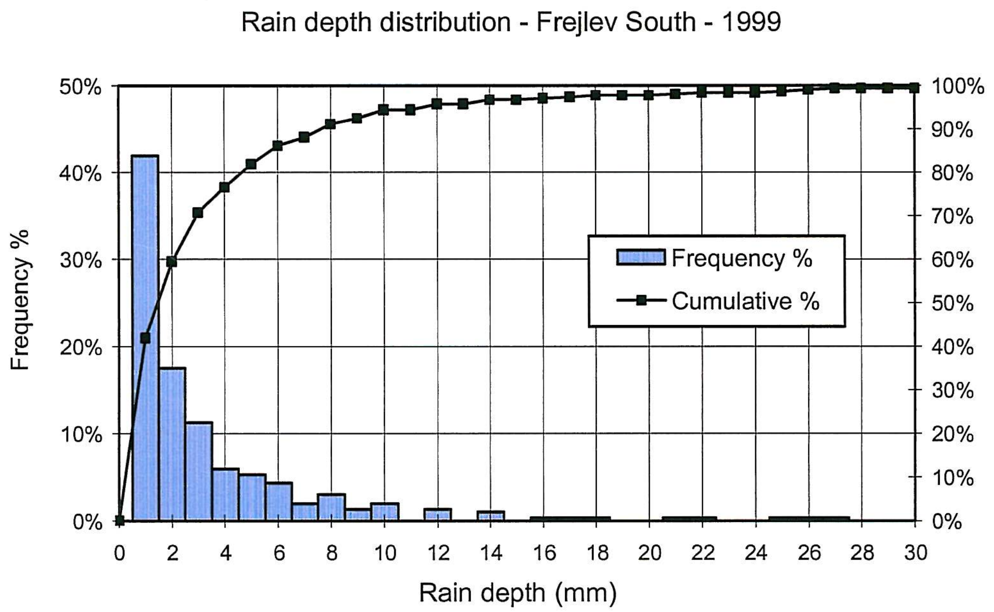

Figure 8: Rain depth distribution, Frejlev South, 1999.

A bold generalization based on 1999 rainfall data could contain this summary:

- approximately 40% of all rainfall events in Frejlev have a rain depth smaller than 1mm
- only 5% of all events have a depth greater than 10 mm, and
- rainfall events with a rain depth of more than 20-30 mm are rare.

3.2 FLOW MEASUREMENTS

Except for 5 days-and-nights flow measurements have been transferred from the Frejlev station to the database at the university. Most likely the flow meters have worked properly during the whole year. The above mentioned outfall period - amounting to 1.4% of the time – was caused by a dropout of the data transmission equipment.

During dry weather periods the day-and-night flow - measured at the station - varies in a typical manner, see figure 8 below (and figure 7 in the1998 annual report):

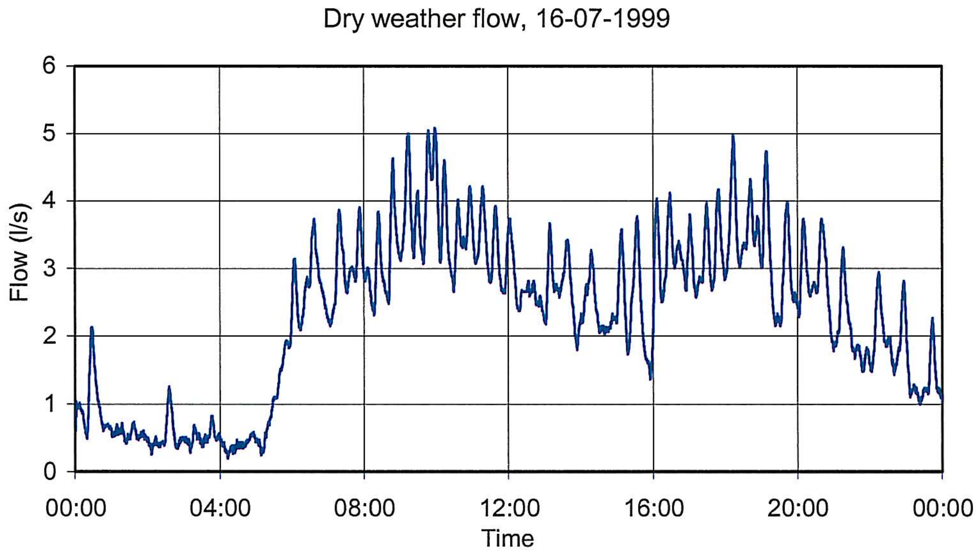

Figure 8: Measured dry weather flow, Thursday 16, July 1999.

From figure 8 it is worth noting the many small peaks which are most frequent and most conspicuous during daytime. These peaks originate from a small waste water pump placed in the south-western part of the city where waste water is pumped into the combined sewer system from upstream located separate sewered catchments.

With reference to the example illustrated in figure 8 the low night flow between 01.00 and approx. 05.00 a.m. indicates a sewer system without any significant infiltration - if any at all. For this reason the dry weather flow in the Frejlev sewer system is assumed to be equivalent to non-diluted waste water flow.

As a part of their M.Sc. study within the field of environmental engineering, several students have analyzed the Frejlev research station flow data - especially the flow data of 1999. Some results from these investigations (Bentzen et al., 2002) are presented below.

This group of students has identified 145 dry weather days-and-nights in 1999 and the annual variation of the diurnal mean dry weather (waste water) flow is illustrated in figure 9. Behind the fluctuations it is possible to distinguish a tendency with a relative low diurnal waste water flow during the period June-November - opposite to a relative high dry waste water flow during the period December-May. The annual mean value of the diurnal waste water flow amounts to 3,3 l/s (simple arithmetic mean) or 285 m^3/day corresponding to 140 litre per person per day (2000 inhabitants). Furthermore, the 1999 maximum diurnal value of the waste water flow exceeds the annual mean value with approximately 40% and correspondingly the 1999 minimum diurnal waste water flow is approximately 30% smaller than the annual mean value.

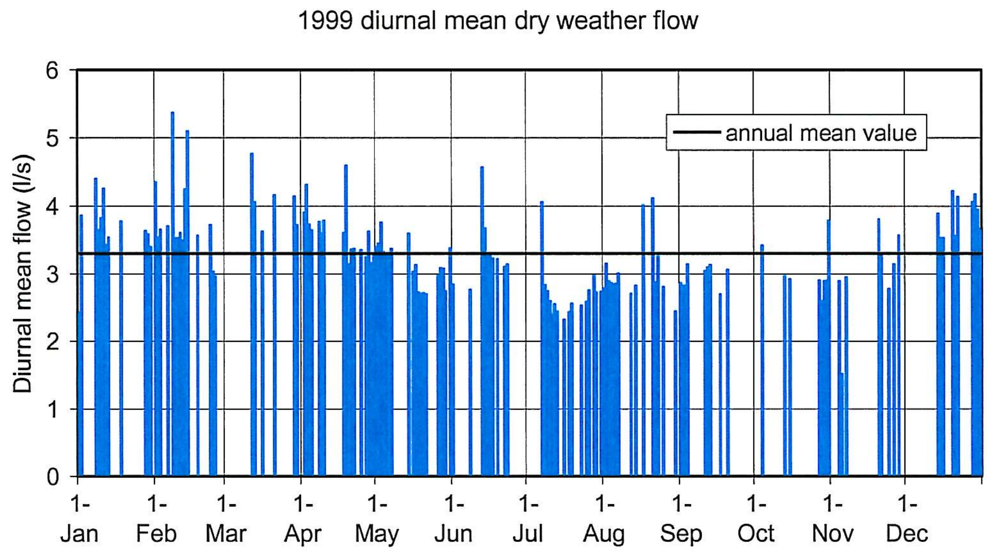

Figure 9: Diurnal mean values of measured waste water flow during 145 dry weather days-and-nights in 1999 – from Bentzen et al. (2002).

According to the results shown in figure 8 and 9, July 16 is the day-and-night among all 145 with the lowest diurnal dry weather flow. Calculations have shown that the diurnal mean flow this very day is 2.2 l/s with a 1 hour mean flow varying between 0.3 and 3.6 l/s, respectively. In this way the 1 hour maximum mean flow exceeds the diurnal mean flow with approx. 65% during this very day. It is noteworthy that this specific 1 hour maximum flow value of July 16 only differs slightly from the annual mean dry weather flow of 3.3 l/s.

This 1 hour maximum mean flow of the diurnal minimum waste water flow presents a special interest in Denmark as this specific flow value traditionally form the flow basis in analyses aiming at uncovering the self cleaning capacity of sewer pipes.

In Frejlev the flow sampling frequency is approx. 3 Hz – i.e. the time between momentary flow values in the database is approx. 20 seconds. Actually the sampling frequency automatically will increase if abrupt flow variations suddenly occur. The above mentioned group of students have constructed the cumulative frequency curve for the momentary dry weather flow - see figure 10 below.

From figure 10 it is evident that the median of these momentary dry weather flow values amounts to approx. 3.3 l/s equivalent to the annual mean value of the diurnal dry weather flow. The figure also illustrates that the 1 hour maximum mean flow (3.6 l/s) of the diurnal minimum waste water flow is exceeded in approx. 40% of the time in dry weather periods. If this is a general pattern of the waste water flow in Danish sewers then many Danish self cleaning capacity analyses are performed based on flow values corresponding to the median waste water flow value.

It is worth noting that this statement as well as figure 10 is based on momentary waste water flow values i.e. without regard to the length of time interval in which overstepping of a specific value is taking place. Overstepping a specific value during a minute is included in the durational percentage on a par with overstepping the value during e.g. one hour. In this context it is important to consider if not the length of the overstepping period is playing an important part for the self cleaning capacity of a sewer system. Further investigations on this issue are planned for the succeeding years.

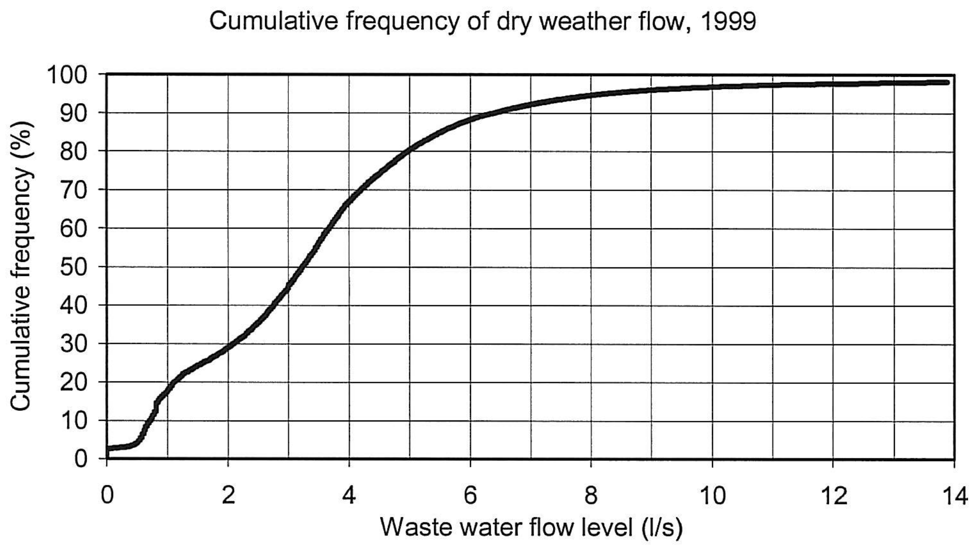

Figure 10: Cumulative frequency of waste water flow level during 145 dry weather days-and-nights in 1999 – from Bentzen et al. (2002).

Another important aspect linked to these considerations is the fact that flow measurements in Frejlev are taking place in a pipe having approx. 2000 inhabitants in the upstream catchments. If similar measurements were performed in pipes having only a small number of inhabitants in the upstream catchments the flow variations are expected to be more distinct.

In 1999 approximately 300 rainfall events have been recorded by the rain gauges and most likely the flow generated by all these events have been recorded by the 2 flow meters. An outfall period in the flow database amounting to 1.4% of the time is due to dropouts of the data transmission equipment.

Investigations still indicate that only 50-60 % of the area of the impervious catchments is connected to the sewer system.

3.3 WATER QUALITY MEASUREMENTS AND SAMPLING

The Frejlev sewer monitoring station is designed for sampling of waste water and measurements of quality parameters during dry as well as wet weather conditions. In addition, it allows performance of small-scale pilot experiments that require continuous supply of fresh waste water. Installations and conditions for sampling and measurements can be flexible arranged to comply with specific and varying demands.

During 1999 waste water from Frejlev has been extensively used for research as well as for student experiments. The daily, the weekly and the yearly variability of the waste water quality is therefore now under dry weather conditions rather well known from a catchment primarily dominated by waste water from residential and institutional sources. This fact is very useful in the planning process of experiments performed at the department.

Numerous research and student projects have made use of the monitoring station for either sampling of waste water for bench scale experiments or in-sewer process studies. In each of these studies, the beneficial use of the monitoring station has played a central role. The Frejlev Research and Monitoring Station has provided waste water samples referred to in the following publications from 1999: Vollertsen et al. (1999a) and Vollertsen et al. (1999b).

4. EQUIPMENT SPECIFICATIONS

Rain:

On top of monitoring structure (Frejlev North)

A tipping bucket rain gauge, bucket capacity: 0.2 mm, produced by Rimco Australia. This gauge (no.: 20458) forms a part of a nation wide rain gauge system operated by the Danish Meteorological Institute on behalf of The Water Pollution Committee of The Society of Danish Engineers.

In the southern part of Frejlev (Frejlev South)

A tipping bucket rain gauge, bucket capacity: 0.2 mm, produced by Rimco Australia. This gauge (no.: 20456) forms a part of a nation wide rain gauge system operated by the Danish Meteorological Institute on behalf of The Water Pollution Committee of The Society of Danish Engineers.

Flow:

In monitoring structure

Electromagnetic flow meter, Parti-Mag II, model DP 4_F, diameter size: 300 mm. Produced by Bailey Fischer & Porter, Göttingen, Germany, 1996, equipment number: A1 9606.

In flow meter structure

Electromagnetic flow meter, Parti-Mag II, model DP 4_F, diameter size: 1000 mm. Produced by Bailey Fischer & Porter, Göttingen, Germany, 1996, equipment number: A2 9606.

Water quality:

In control structure and monitoring structure

Non-stationary sampling, monitoring equipment and reactors for specific project purposes.

Data transmission:

In monitoring structure

2 measurement radio stations (8 bit) with 5 analog channels, 8 input and 8 output digital channels, produced by Teletronic, Copenhagen Research Center, Denmark.

Aalborg University, Sohngaardsholmsvej 57, Aalborg

1 main 8 bit radio station for max. 64 measurement stations, min. 12 kilometers reach, produced by Teletronic, Copenhagen Research Center, Denmark.

5. EXTRACTION OF DATA FROM DATABASE

The measurements in the Frejlev station of rainfall and flow data has been placed as time series in a database at the Department of Civil Engineering, Aalborg University. Till now this database do not contain any water quality data at all – cf. section 3.3. At present it is not decided if water quality data shall be a part of the rainfall-flow database due to natural differences in dataformat between these 2 types of data. It might therefore be decided to form 2 databases for these 2 data types or time series of which the rainfall-flow time series is continuous while the water quality time series will be discontinuous due to limited resources.

The owners of the station have decided that this (these) database(s) shall be accessible to the general public for payment. For the cost price data can be extracted from the database(s) to a CD-ROM disk together with a post-processing program.

Application for extraction of data must be passed to:

Assoc. Prof. Kjeld Schaarup-Jensen,
Hydraulics and Coastal Engineering Group,
Department Of Civil Engineering,
Aalborg University,
Sohngaardsholmsvej 57, DK-9000 Denmark.
Phone: +45 96 35 84 83
Email: kjeld.schaarup.jensen@civil.auc.dk

6. PUBLICATIONS RELATED TO THE STATION

A number of publications produced at the Department of Civil Engineering include results based on data performed at the Frejlev sewer research and monitoring station. Faculty at the Environmental Engineering Laboratory or at the Environmental Hydraulics Group dealing with sewer systems and processes produces all these publications. Only publications including a substantial amount of data from the station will be mentioned.

Schlütter, F. and K. Schaarup-Jensen (1997). Sediment transport in a small urban catchment under dry weather conditions, proceedings for the 2nd International Conference on The Sewer as a Physical, Chemical and Biological Reactor, Aalborg, Denmark, May 25-28, 1997.

Schaarup-Jensen, K., Thorkild Hvitved-Jacobsen, Bent Jütte, Bjarne Nielsen and Tage Pedersen (1998). A Danish Sewer Research and Monitoring Station, *Water Science and Technology,* vol. 37, no. 1, 197-204.

Schlütter, F. and K. Schaarup-Jensen (1998). Sediment transport under dry weather conditions in a small sewer system, *Water Science and Technology*, vol. 37, no. 1, 155-162.

Vollertsen, J., M. do C. Almeida and T. Hvitved-Jacobsen (1999a). Effects of temperature and dissolved oxygen on hydrolysis of sewer solids. *Water Research,* vol. 33, no. 14, 3119-3126.

Vollertsen, J. and T. Hvitved-Jacobsen (1999b). Stochiometric and kinetic model parameters for microbial transformations of suspended solids in combined sewer systems. *Water Research,* vol. 33, no. 14, 3127-3141.

7. REFERENCES

Frich, Poul, Stig Rosenoern, Henning Madsen and Jens Juncher Jensen (1997), Observed Precipitation in Denmark, 1961-90, Technical Report 97-8, Danish Meteorological Institute, Ministry of Transport.

Bentzen, T. R., Cernat, D. L., Hestbech, A., Moelbye, N., Noerskov, N. D., Pedersen, L. and Thorndahl, S. (2002). A Study of the Frejlev Sewer System (in Danish), M.Sc. study report, Water & Environment Engineering, Aalborg University.

Johansen, N. B. (1985). Discharge to Receiving Waters from Sewer Systems during Rain, Ph. D. Thesis, Department of Environmental Engineering, Technical University of Denmark, pp. 287.

Harremoës, P. (1988). Stochastic models for estimation of extreme pollution from urban runoff, Wat. Res. 22 (8), 1017-1026.

House, M.A., J. B. Ellis, E. E. Herricks, T. Hvitved-Jacobsen, J. Seager, L. Lijklema, H. Aalderink and T. Clifford (1992). Urban drainage - impacts on receiving water quality, Wat. Sci.Tech., 27, 117-158.

Hvitved-Jacobsen, T. and Y.A. Yousef (1991). Highway runoff quality - environmental impacts and control, chapter 5, 165-208. In: R.S. Hamilton and R.M. Harrison (eds.), Highway Pollution, Studies in Environmental Science, 44, Elsevier Science Publishers, Amsterdam.

Hvitved-Jacobsen, T., J. Vollertsen and P. H. Nielsen, (1997). A conceptual model for microbial waste water transformations in gravity sewers, proceedings for the 2nd International Conference on The Sewer as a Physical, Chemical and Biological Reactor, Aalborg, Denmark, May 25-28, 1997.

Nielsen, M. Kjoerup, February 2000. Operation of the rain gauge system of the Danish Wastewater Committee, Technical Report 00-03, Danish Meteorological Institute, Ministry of Transport.

Schaarup-Jensen, K. and T. Hvitved-Jacobsen, (1990). Dissolved oxygen stream model for combined sewer overflows. Wat. Sci. Tech., 22 (10/11), 137-146.

Schaarup-Jensen, K. and T. Hvitved-Jacobsen, (1991). Simulation of dissolved oxygen depletion in streams receiving combined sewer overflows, in New Technologies in Urban Drainage, ed. Maksimovic, C., UDT '91, Dubrovnik, Yugoslavia, 273-282.

Schaarup-Jensen, K. and Hvitved-Jacobsen, T. (1994). Causal stochastic simulation of dissolved oxygen depletion in rivers receiving combined sewer overflows. Wat. Sci. & Tech., 29, 191-198.

Schlütter, F. and K. Schaarup-Jensen (1997). Sediment transport in a small urban catchment under dry weather conditions, proceedings for the 2nd International Conference on The Sewer as a Physical, Chemical and Biological Reactor, Aalborg, Denmark, May 25-28, 1997.

Tanaka, N. and T. Hvitved-Jacobsen (1997). Domestic waste water quality transformations during transport in sewers under changing aerobic/anaerobic conditions, proceedings for the 2nd International Conference on The Sewer as a Physical, Chemical and Biological Reactor, Aalborg, Denmark, May 25-28, 1997.

Vollertsen, J. and T. Hvitved-Jacobsen (1997). Aerobic microbial transformations and related modelling of resuspended sediments in combined sewers, proceedings for the 2nd International Conference on The Sewer as a Physical, Chemical and Biological Reactor, Aalborg, Denmark, May 25-28, 1997.